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Power Required to
Run Machine Tools

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POWER REQUIRED TO RUN MACHINE TOOLS

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

CHRIS BEACH WATROUS

ENTITLED POWER REQUIRED TO RUN MACHINE TOOLS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Mechanical Engineering

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POWER REQUIRED TO DRIVE MACHINE TOOLS.

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Introduction.

The last century has witnessed a great change in the manufacturing industry, and to meet this change has become a great engineering problem.

When manufacturing first became an industry the factor of time of production was a minor item, while quality was the object in view. At the present time, however, when this branch of industry is at its height, we are confronted with the problem of producing the finest quality in the shortest possible time.

Supposing we have the factor, quality, fixed and deal only with the variable—time; we wish to know what quantities affect this element and they are found in the machine shop, which next to nature is one of the greatest producers in the world.

The most important of these quantities is the problem of the machine tool which is to turn out the finished product, and now arises the question of the power required to drive this tool to which the following pages are devoted.

The situation is summed up very thoroughly in a discussion on motor drives by Mr. Townly of the Westinghouse Electric Company as follows:

"Practically all forms of transmission dynamometers depend on the diversion or deflection of some part of a train of transmitting mechanism, which deflection varies in accordance with a known law, proportionately to the power transmitted and by means of a suitable indicating or recording device, such amount of power is made known."

Whether it be from distrust of accuracy of these devices or from complexity of the adjustments necessary to secure good results, there appears to be a prevalent and well defined objection, among mill men and engineers, to the use of these devices wherever it can be avoided, and in considering the question of the consumption of power by textile as well as other machinery we are continually confronted with the fact that this power has never been measured and that the operators knowledge of the amount and distribution is limited to that obtained by indicating his engines and calculating the general distribution roughly by the speeds and widths of his belts; which is of course, at best, only approximate and gives no indication of the distribution of power between countershafting and the machinery which does useful work.

In the rapidly increasing use of electric motors in mills and factories of all kinds, the question of sub-dividing the power becomes a vital one and requires immediate solution. It is necessary to know definitely whether a certain number of machines actually require for their operation 30, 40 or 50 horse-power and it is possible to effect very large savings in the cost of power as well as in cost of electrical apparatus furnishing it, by the accurate determination of this distribution. This determination by means

of an electric motor is simple, immediate and accurate within the closest desired range.

The use of an electric motor presupposes that the electric current is available and therefore measurements of power consumed may be readily and quickly made. For this purpose a motor of suitable capacity may be mounted on a stout hand truck and this moved from one machine to the next to be tested.

Probably the most important of all power driven machines is the lathe and so it will be taken up first.

It has been found by experiment that it requires more power to drive a lathe empty, running at full speed, with cone disconnected and loose, than to drive with back gear and spindle thrown in; also that from one-half to 1-1/2 more horse-power is required to drive the machine when all the parts are cold than after it has been running an hour or so, in which time the bearings have become warm.

Most engineers who have done any experimenting along these lines agree that one of the most important factors entering into this problem is the shape of the tool used and the material of which it is constructed, consequently any data is decidedly incomplete without the material of which the tool is composed and a fair idea of the cross-section of cut, this being the result of the shape of cutting edge of tool.

If the cut is very nearly square in section the amount of power required would be a minimum, and if very wide and thin it would be a maximum. This amount of power depends almost altogether upon the sharpness of tool and upon form of cut. If it is comparatively square in section and the feed is about equal to the depth of cut, it is not a serious matter to have a dull tool. The metal is

broken away from the head of the tool as though it were a wedge and the edge of the tool hardly reaches the metal at the point. It piles up on the edge of the tool and forms a wedge. From many experiments it has been found that the resistance per square inch of metal varies from 700,000 to 180,000 pounds for steel; cast-iron, about one-third per square inch of section removed.

The dullness of a tool effects but little the power required with a heavy cut, but in taking a light cut it is very necessary to have a sharp tool and much depends on keeping it sharp.

The two following tables I and II were taken from the thesis of Mr. F. L. Drew, '04, in which he used a transmission dynamometer, taking cards from a steam indicator by oil pressure.

TABLE I.

UNIV. OF ILL. TURNING 2 15/16" STUD SHAFT IN 20-IN LATHE.
TOOL OF MUSCHIE STEEL.

F. L. DREW.

No	Time in Min.	Diameters inches. d'	d"	Depth of Cut in.	Breadth of Cut in.	R.P.M. of Spindle.	Travel of Tool in.	Cutting Speed Ft. per Min.	Metal Removed Per Hour.	I.H.P.	Lathe H.P.
1	3	—	—	0	0	25.2	0	0	0	0.242	0.234
2	5	2 15/16	2 3/16	3/8	.052	42.0	1.07	5.62	10.8	0.514	0.498
3	5	"	2 1/8	13/32	.025	"	1.05	5.50	11.3	0.534	0.518
4	5	"	2 5/32	25/64	"	42.5	1.08	5.10	11.6	0.501	0.486
5	5	"	2 29/32	33/64	"	41.0	1.03	5.23	13.8	0.568	0.551
6	20	"	1 15/16	1/2	.030	168.0	5.00	5.36	16.0	0.680	0.659
7	15	"	1 15/16	1/2	.022	132.0	2.95	5.61	12.6	0.569	0.552

TABLE II.

19" CAST-IRON CAR-WHEEL IN SAME LATHE.

1	5	18 15/16	18 7/16	1/4	.033	26	7/8	25.5	40.8	0.850	0.824
2	"	18 7/16	18 1/16	3/16	.025	27	11/16	25.8	21.4	0.688	0.667
3	"	18 1/16	17 9/16	1/4	.026	26	"	24.2	30.0	0.800	0.853
4	"	17 9/16	17 1/8	"	.026	26	"	23.5	30.0	0.750	0.727
5	10	17 1/8	16 21/32	15/64	—	—	1 3/16	—	24.1	1.834	0.810
6	15	16 21/32	16 5/32	1/4	.025	79	2 1/64	22.5	27.0	1.190	1.150
7	12	16 5/32	16 29/32	1/8	.039	63	2 11/32	22.0	21.3	0.896	0.869

Some information bearing on this subject is obtained from a paper presented at the 229th Meeting of the New York Electrical Society on December 17, 1902, by Charles Day. In this paper he says that the thing to keep in mind is that the object of our work should be to execute a job most efficiently the first time in the shop; efficiency being used in the broadest sense and not necessarily implying that the cheapest production be arrived at, as attained when manufacturing in quanity, since special tools as are frequently required in such a case would not be justified.

Supposing the castings have been received in the shops and the method of machining determined upon; a certain amount of metal has to be removed and a definite finish is required; our object being to accomplish this result in the least possible time, or rather, at the least expense. Most manufacturing concerns order their castings to a size which will require a minimum amount of machining and to do this in the shortest time requires the very best of steel for the tool.

Now, when we have the required tool we are back to the old problem of the power required to drive this tool, and it is surprising how little these same manufacturers know about it. The author of this circular received the following reply from a certain well known manufacturer of machine tools: We have never made any tests as to the power used to drive machine tools, but when we make motor driven lathes we put a 1 H. P. motor on a 14-inch lathe; on a 16-inch and 18-inch lathe a 2 H. P. motor, and on a 20-inch or 22-inch a 3 H. P. motor for ordinary work. What could be more indefinite than this? The same company might do double the amount of work with these lathes if a more powerful motor were used with the proper steel, by removing just twice the amount of metal per hour.

Table III is taken from the paper mentioned above, by Charles Day, and is a portion of a record of 125 tests on various tools, depth of cut and feed being constant and speed varied so that tool would last just 20 minutes.

The accompanying curve covers the principal data relating to Driving Mechanism of Bullard Boring Mill and shows at once the cuts that can safely be removed on any diameter at any speed. The motor horse-power is also plotted and the over load that the gears are subjected to is clearly shown; the whole chart making it plain that a great many factors must be considered if the subject is to be treated thoroughly.

As the horse-power is first figured from the maximum cut to be removed, an investigation of the machine for strength is very necessary, and also the gears connected with driving mechanism; it is a well known fact that for a given cutting speed the least cross section of cut that can be removed is at the lowest spindle speed.

Many manufacturers of motors have endeavored to show by exact figures the advisability of using individual motors, but in nearly every case such reasoning has always proved most unsatisfactory.

In connection with his paper on the motor drive, Charles Day says: We must study present conditions and in each case see how much they will be bettered by the use of a motor. Crane service alone may be ample reason for its adoption, or, again, when the intelligence of the men or facilities offered, make it possible to run each tool to its limit.

We must ever remember that the belt drive, as applied to most machines, does not permit of running to the tool limit on the average job, while the motor, if properly installed, offers the opportunity. It can do nothing more.

TABLE III.

EXPERIMENTS ON CUTTING SPEEDS

DODGE & DAY. NOV. 24, 1902.

RIGHT HAND ROUGHING TOOL OF 1¾" X ⅞" SELF HARDENING STEEL.

CLEARANCE ANGLE OF TOOL: — 8°

RAKE ANGLE OF TOOL { FRONT: — 2° ; SIDE: — 20° }

TOOL CUTTING: - DRY.

№	Feed	Depth of Cut	Cutting Speed Ft. per min.	Mark on Tool	Duration of Cut in min.	Dia. at Top of Cut inches.	Dia. at Bottom of Cut inches.	Tool Started from Top End inches.	Volts.	Amperes.	H.P. (Slide Rule)	Total Longitudinal Feed of Tool inches	Remarks.
24	0.0606	3/16	97.0 91.7	Taylor W. H.S.H. № 1.	16¼	21⅜	21	0	130 134	30 5	5.23	16⅛	Ruined
25	"	"	103.0 100.0	Capitol № 1.	20	"	"	16⅛	170 172	24 5	5.47	21¾	Fair
26	"	"	105.5 104.0	Capitol № 2.	20	"	"	37⅞	171 172	24 5	5.55	22 11/16	Good
27	"	"	104.0 101.0	Capitol № 3	13	21	20⅝	0	167 170	27 5	6.05	14½	Ruined
28	"	"	104.0 101.0	Taylor W № 1.	11¼	"	"	14½	164 172	26 5	5.71	12½	"
29	"	"	100.0 99.1	Jessop № 1.	20	"	"	27	132 135	26 5	4.60	20⅞	Good
30	"	"	105.0 101.0	Jessop № 2.	20	20⅝	20¼	0	166 167	24 5	5.34	22 11/16	Ruined
31	"	"	107.0 197.5	Jessop № 1.	20	20⅝	"	22 11/16	168 170	24 5	5.41	23	Good
32	"	"	115.5 111.5	Jessop № 4.	13	"	"	45 11/16	168 170	25 5	5.63	16¼	"
33	"	"	125.0 115.0	Jessop № 3.	2 1/12	20¼	19⅞	0	166 170	28 5	6.23	2¾	Ruined
34	"	"	118.0 109.0	Jessop № 2.	10¾	"	"	2¾	167 170	28 5	6.27	13 3/16	"

If we cannot accurately figure beforehand what economy will result from the use of the motor, it may at least be of interest to investigate the records of shops which have made such installations, as a means of comparison is thus afforded.

We must, however, be very careful not to draw too hasty conclusions as to the merits of the apparatus from such investigations, as the experiment is utterly useless without the management and organization behind it.

The inefficiency of the belt and step cones, as a means of machine tool driving, even when installed is such a way as to permit of good crane service, is too well understood to demand much attention here. It is not a question of does it fulfill present conditions, but will it meet the new requirements resulting from the advance in tool steel, and our better knowledge on the subject. It certainly will not.

The American Machinist for January 7, 1904, gives some very important results on High-Speed Tool-Steel tests by the Lodge and Shiply Machine Tool Company, but since this circular deals with the power required to drive these tools, only Table IV is reproduced in this connection.

The lathe used was a Lodge & Shiply 20-inch, equipped with a high speed headstock and tailstock and a double tool rest. The spindle was exclusively gear driven, with two changes of speed, ratios from pulley to spindle being 3 to 1 and 9 to 1. For this test the lathe was motor driven as the quotient obtained by dividing the power of voltage and amperage by 746 gives horse-power required to drive lathe, motor and to do useful work in removing metal.

It was clearly demonstrated during these tests that at the higher speeds much more power was consumed to remove a given amount of metal than at the slower speeds, also that the angle of the tool made quite a difference as is illustrated by tests 87, 88 and 89, each being under the same conditions, except that the angle of the top of tool was changed in each case.

The tool was of air hardened steel, tempered at a high degree of heat in oil and was in very good shape after the experiments. From this and other tests the same tool steel was found to be far superior to any of seven other and respectively different brands.

TABLE IV.

CAPACITY AND H.P. TEST OF LODGE & SHIPLEY 20-IN LATHE.

AM. MACH., JAN., 7, 1904.

No	Feed.	Depth of Cut	Cutting Speed, Ft. Per Min.	Total Longitud. Feed of Tool in.	Duration of Cut in min.	H.P. Machine and Cut.	Remarks.
87	2/15	1/16	175	21	50 s	17	Tool of air-hardening
88	"	"	"	"	"	19	tool-steel, tempered in
89	"	"	"	"	"	13.6	oil.
90	1/15	"	"	"	40 s	15.9	
99	1/10	"	121	"	1.28	7.2	
100	"	"	"	"	"	7.7	
101	"	"	"	"	"	7.1	Back Gear Sleeve
102	"	"	"	"	"	9.0	Forgings: Total time of
103	"	"	"	"	"	9.0	Handling and Turning
104	"	"	"	"	"	7.7	8 in 24 min or 20 per hr.
105	"	"	"	"	"	8.0	
106	"	"	"	"	"	7.2	
113	"	3/8	66	6	—	15.4	
114	1/80	1/32	342	7	1.40	3.4	
116	1/40	1/16	340	11	—	5.4	
						H.P. of Cut only.	
108	1/30	1/2	108	24		15	
109	1/22	"	128	"		17	
110	1/20	"	128	"		19	
111	1/20	"	160	"		30+	
112	1/8	"	92	"		22½	

In connection with his experiments on line shafting, which follow, Victor L. Sheldon gives a small table of results made on a 26-inch Reed lathe at the University of Illinois. The material machined was a piece of machine steel 2-1/2 inches in diameter and 30 inches long. The tool was sharpened before each cut and conditions surrounding the cutting edge of the tool were kept constant throughout the experiments.

We find in this table values for the constant C in the empirical formula H. P. = C W when C is a constant varying for different metals and W is the weights of metal removed per hour.

TABLE V.

TURNING CAST IRON IN 26-IN REED LATHE.
AT UNIV. OF ILL. V. L. SHELDON.

No	Reduction of Diameters inches	Cutting Speed Ft. Per Min.	Feed inches	Average H.P. Required to Remove Metal.	Weight of Metal Removed per Hr. W.	Value of Constant C	Tool Used.
1	$2\frac{1}{2}$: 2	15.4	.0353	1.106	25.10	.0432	Hog Nose
2	2 : $1\frac{1}{2}$	13.2	.0422	1.009	23.64	.0426	" "
3	$1\frac{1}{2}$: $1\frac{11}{32}$	18.9	.0375	0.485	11.76	.0414	Round Nose

Some very good results are given by Mr. C. H. Benjamin in Machinery March, 1899, which was made at the Baldwin Locomotive Works. The machines were motor driven (independently) thus affording a convenient method of measuring power required to drive. Again we have presented the large amount of power consumed by motor and countershaft, which when averaged up for sixteen cases gives a loss of 25 per cent. of power which goes to run motor and shaft.

In the second table given here, we have the net horse-power, that is without countershaft and from the values in table it is very evident that more power was required to run the empty table when the stroke was short than when long. The experiments marked 1 to 6 were made by a Webber dynamometer while those from 7 to 9 were made by a Flather recording dynamometer. From the fact that the maximum record of the shaper was 35 pounds per H. P. per hour and that of the planer 20 pounds per H. P. per hour, also knowing that the shaper was the smaller of the two, we see the advantage of moving the tool over that of moving the work and holding the tool stationery.

TABLE VI.

COMPARISON OF VARIOUS MACHINE TOOLS.

FOR DRIVING H.P.

BALDWIN LOCOMOTIVE WORKS. C.H. BENJAMIN.

Machine.	Size.	Material Cut.	No. of Tools.	Horse-Power.				
				Motor and Shaft.	Machine Empty.	Total Cutting		
						Min.	Max.	Ave.
Wheel Lathe	84"	Cast Iron	2	—	—	2.9	7.9	6.1
" "	"	" "	"	—	—	4.2	5.8	5.1
" "	"	" "	"	—	1.5	5.3	6.2	5.8
Boring Mill.	78"	" "	1	—	—	4.3	4.7	4.5
" "	"	" "	"	—	—	5.5	7.1	6.5
Slotting Machine	36" x 12"	Wro't Iron	"	1.50	1.5	4.4	6.7	5.3
Sellers Planer	62" x 35 Ft.	" "	2	4.40	11.4	20.6	21.6	21.1
" "	" "	" "	"	—	5.8	23.0	26.0	24.5
Planer	36" x 12 Ft.	" "	"	2.70	3.0	11.3	13.8	12.5
Bement Planer	24" x 13 Ft.	Steel	"	1.95	4.3	—	—	8.0
Sellers "	36" x 18 Ft.	Wro't Iron	"	3.20	4.3	—	—	16.7
" "	56" x 35 Ft.	" "	"	4.60	9.9	13.0	13.7	13.3
" "	56" x 24 Ft.	" "	"	4.56	6.0	16.0	17.7	16.8
Wheel Lathe	90"	Cast Steel	"	1.43	2.1	—	—	6.38
Bement Drill.	21 Ft.	Wro't Iron	3 - 7/8"	2.10	2.6	3.6	4.8	4.2
" "	"	" "	3 - 2"	2.10	2.6	—	—	8.0
Harrington Drill.	22 Ft.	" "	2 - 1"	1.10	1.45	2.7	5.15	3.7
Radial Drill	42"	" "	1 - 2"	0.96	1.1	—	—	2.1
Boring Mill	4 Ft. 6"	Cast Steel	1	2.10	2.4	—	—	4.6
" "	5 Ft. 6"	Cast Iron	"	1.60	2.4	4.2	4.8	4.4
Slotting Machine	40" x 15"	Wro't Iron	"	1.80	2.2	—	—	7.3
Shaping Machine.	19" Str.	" "	"	1.60	1.8	4.8	9.7	7.3

MACH., MAR., 1899.

TABLE VII.

COMPARISON OF DRIVING H. P. FOR PLANER AND SHAPER.
BALDWIN LOCOMOTIVE WORKS. C. H. BENJAMIN.

No	Machine	Size	Material Cut.	Pounds Metal Removed Per Hour	Horse-Power		
					Empty Forward	Empty Return	Machine Cutting
1	Gray Planer	24" x 6 Ft.	Cast Iron	—	.24	.62	0.50
2	" "	" "	" "	14.1	.20	.64	0.54
3	" "	" "	Machinery Steel	18.0	.17	.37	0.95
4	" "	" "	" "	12.1	.33	.65	0.92
5	" "	" "	" "	21.2	.33	.62	1.35
6	" "	" "	" "	—	.23	.47	0.94
7	" "	" "	Cast Iron	13.7	Ave. .64	—	1.03
8	" "	" "	" "	21.7	" .64	—	1.29
9	" "	" "	" "	24.7	—	—	1.58
10	Hendey Shaper	16"	" "	10.5	Ave. .153	—	0.44
11	" "	"	" "	8.7	" .153	—	0.25
12	" "	"	" "	13.5	" .153	—	0.77

MACH., MAR., 1899.

The tests given in Table VIII on Engine lathes gives net horse-power consumed by lathes; since the function of countershaft is deducted. Experiments numbered 1 to 5 were made with the Webber dynamometer and the remainder with the Flather instrument. No. 8 shows minimum and maximum power required to run the empty lathe, various speeds and combinations of years having been tried. No. 10 shows effect of screwing the foot spindle up against the work when tool was not cutting and No. 14 shows the effect of a hot box on the main spindle.

TABLE VIII.

DYNAMOMETER TESTS ON ENGINE LATHES.

No	Machine	Size	Material Cut.	Pounds Metal Per Hour	Net Horse-Power		
					Empty.	Cutting	
						Min.	Max.
1	Putman Lathe	16" x 8 Ft.	Cast Iron	—	.03	.22	.27
2	" "	" "	Mach'y Steel	—	.04	.25	.30
3	Flather Lathe	22" x 6 Ft.	" "	5.3	.09	.28	.44
4	" "	" "	Cast Iron	9.1	.07	—	.26
5	" "	" "	" "	15.0	"	—	.47
6	" "	" "	" "	19.6	"	—	.81
7	" "	" "	" "	14.9	"	—	.62
8	" "	" "	Not Cutting	—	—	.07	.30
9	" "	" "	Cast Iron	20.6	—	—	.53
10	" "	" "	Tight Centre	—	—	.25	.58
11	Putman Lathe	16" x 8 Ft.	Mach'y Steel	5.7	.08	—	.54
12	" "	" "	" "	8.2	"	—	.64
13	" "	" "	" "	9.0	"	—	.71
14	" "	" "	Hot Box	—	—	—	1.05

On of the strong points in connection with motor driven lathes is the saving of the power lost in driving many feet of line shafting and the countershafts of each lathe. This friction load depends upon the condition of the shafting, speed, size and number of belts and alignment of hangers. From a series of tests Mr. H. H. Holding found:

Factory No. 1. Average load 98.6 H. P. Average friction load 65.7 H. P., useful energy 22.9 H. P., efficiency at average load 24%.

Factory No. 2. Average load 166 H. P., friction load 78 H. P. average useful energy 88 H. P., efficiency at average load 53%.

Factory No. 3 Average load 220 H. P. Average friction load 49.8 H. P., efficiency at average load 77%.

Victor L. Sheldon in dynamometer tests run on shafting at the University of Illinois found that the H. P. per 100 feet of shafting ranged from 1.02 to 2.3 average distance between bearings being 10 feet and shaft running at about 124 R. P. M.

As was mentioned before Mr. C. H. Benjamin carried on extensive experiments in this line and some very interesting results are given in Table IX covering considerable ground in machine tool work.

In determining the total power which will be required in a given shop, it is necessary to know approximately the proportion of power absorbed by the counters, belting and line shafts. In connection with this the horse-power per countershaft seems to be the most convenient factor, being quite uniform.

TABLE IX.

POWER LOST IN DRIVING LINE SHAFTING.

C.H. BENJAMIN.

Nature of Work.	Total H.P.	Percent to Drive Shafting	State of Load	H.P. Per 100 Ft. of Shafting	H.P. per 100 lbs. of Shafting	H.P. Per Bearing	H.P. of Belt.
Wire Drawing and Polishing	400	39	½	14.00	0.58	1.37	1.76
Steel Stamping and Polishing	74	77	⅓	9.80	0.35	0.84	2.40
Boiler and Machine Work.	38	65	⅔	4.77	0.21	0.55	0.48
Bridge Machinery.	59	81	1	3.28	0.14	0.34	0.52
Heavy Machine Work.	114	57	1	5.70	0.23	0.58	0.45
Light " "	40	51	1	2.75	0.27	0.20	0.09
Manufacturing Small Tools.	74	54	1	8.00	0.40	0.69	0.12
" " "	47	52	1	2.50	0.23	0.24	0.11
Sewing-Machines Etc.	190	57	1	4.36	0.43	0.39	0.21
" "	107	70	1	5.08	0.13	0.41	0.15
Screw-Machines and Screws	241	47	1	6.33	0.38	0.63	0.23
Steel Wood Screws.	117	14.5	¼	2.53	0.11	0.18	0.13

TABLE X

HORSE-POWER LOST IN SHAFTING.

C. H. BENJAMIN.

Nature of Work	Friction Horse-Power						Useful H.P.	
	Per 100 ft. of Shafting	Per 100 lbs of Shafting	Per 100 Sq. ft. of Shafting	Per Bearing	Per Counter Shaft	Per Belt	Per Machine	Per Man
Boiler Shop.	4.77	.205	.040	.550	.538	.477	.310	.877
Bridge Work.	3.28	.137	.040	.337	.606	.521	.164	.142
Heavy Machinery.	5.70	.233	.038	.581	.665	.453	.707	.160
" "	8.55	.306	.060	.709	.600	.475	.627	.342
Average	5.57	.220	.044	.567	.602	.481	.452	.380
Light Machinery.	2.75	.276	.034	.204	.155	.095	.790	.099
Small Tools.	8.00	.400	.090	.689	.127	.119	.109	.152
" "	2.49	.233	.030	.240	.121	.113	.881	.227
Sewing Machines.	4.36	.430	.050	.397	.269	.208	.180	.204
" "	5.08	.134	.034	.406	.172	.154	.181	.003
Screw Machines	6.33	.381	.050	.633	.291	.235	.296	.396
Average	4.83	.309	.048	.428	.189	.154	.406	.195

In the following table the Bickford Drill & Tool Company give the results of a series of tests which are much more complete than any others to be found at present. This copy, taken from the American Machinist September 18, 1902, will be seen to cover drills from one-half inch to 3 inches in diameter and under feeds up to the 1-1/2 inch drill and from .007 inches to .0249 inches beyond that size.

The electrical motor used was a constant speed machine and since the figures for the horse-powers were taken from the current readings they include the power required to drive the motor as well as motor losses.

The tests were made on one of the latest No. 1 Bickford "New Radial" machines, using cast iron. Consulting the table the first thing that strikes the reader is the sudden increase in power required to drive the machine with the 1-3/4 inch drill. This power will be seen to progressively decrease as the speed is reduced up to this point when it jumps up to again resume its downward course, with, however, an increase at the end. The cause of this may be from the addition of another gear in the driving train although the operator claimed that the explanation lay in the drill itself. It is noticeable from the figures in the last column that a very constant amount of power per cubic inch is used for a wide range of diameters of drills.

TABLE XI.

BICKFORD RADIAL DRILL ON CAST-IRON.

AM. MACH., SEPT. 18, 1902.

No	Diameter of Drill	Feed per Revol.	R.P.M.	No Cubic In. Removed per Min.	H.P. Consumed			H.P. Consumed per Cubic In.	
					By Machine	By Work	Total	By Work	Total
1	1/2"	.0070	299	.411	1.23	.65	1.88	1.58	4.58
2	"	.0097	"	.569	1.28	.93	2.21	1.63	3.88
3	"	.0133	"	.781	1.39	88	2.27	1.13	2.90
4	"	.0180	"	1.060	"	1.36	2.75	1.28	2.59
5	"	.0249	"	1.460	"	1.91	3.30	1.31	2.26
6	"	.0346	"	2.030	"	2.36	3.75	1.16	1.85
7	"	.0474	"	2.780	"	5.00	6.39	1.80	2.28
8	3/4"	.0070	206.5	.638	.72	.83	1.55	1.30	2.43
9	"	.0097	"	.885	"	1.19	1.91	1.34	2.16
10	"	.0133	"	1.210	"	1.34	2.06	1.11	1.70
11	"	.0180	"	1.640	"	1.58	2.30	.96	1.40
12	"	.0249	"	2.270	"	2.15	2.87	.947	1.26
13	"	.0346	"	3.160	"	2.85	3.57	.902	1.13
14	"	.0474	"	4.360	"	4.91	5.63	1.13	1.29
15	1"	.0070	143	.786	.46	.70	1.16	.891	1.48
16	"	.0097	"	1.090	"	1.06	1.52	.972	1.39
17	"	.0133	"	1.500	"	1.42	1.88	.946	1.25
18	"	.0180	"	2.020	"	2.02	2.48	1.000	1.23
19	"	.0249	"	2.800	"	2.27	2.73	.811	.976
20	"	.0346	"	3.890	"	3.29	3.75	.846	.965
21	"	.0474	"	5.320	"	3.81	4.27	.716	.803
22	1 1/4"	.0070	99	.852	.31	.87	1.18	1.020	1.390
23	"	.0097	"	1.180	"	1.18	1.49	1.000	1.260
24	"	.0133	"	1.610	"	1.44	1.75	.888	1.080
25	"	.0180	"	2.180	"	1.64	1.95	.752	.894
26	"	.0249	"	3.220	"	1.93	2.24	.638	.742
27	"	.0346	"	4.200	"	2.42	2.73	.576	.650
28	"	.0474	"	5.750	"	3.38	3.69	.588	.642
29	1 1/2"	.0070	82	1.01	.24	.74	.98	.725	.960
30	"	.0097	"	1.40	"	1.25	1.49	.892	1.060
31	"	.0133	"	1.92	"	1.61	1.85	.838	.963
32	"	.0180	"	2.60	"	2.33	2.57	.896	.988
33	"	.0249	"	3.59	"	3.24	3.48	.902	.970

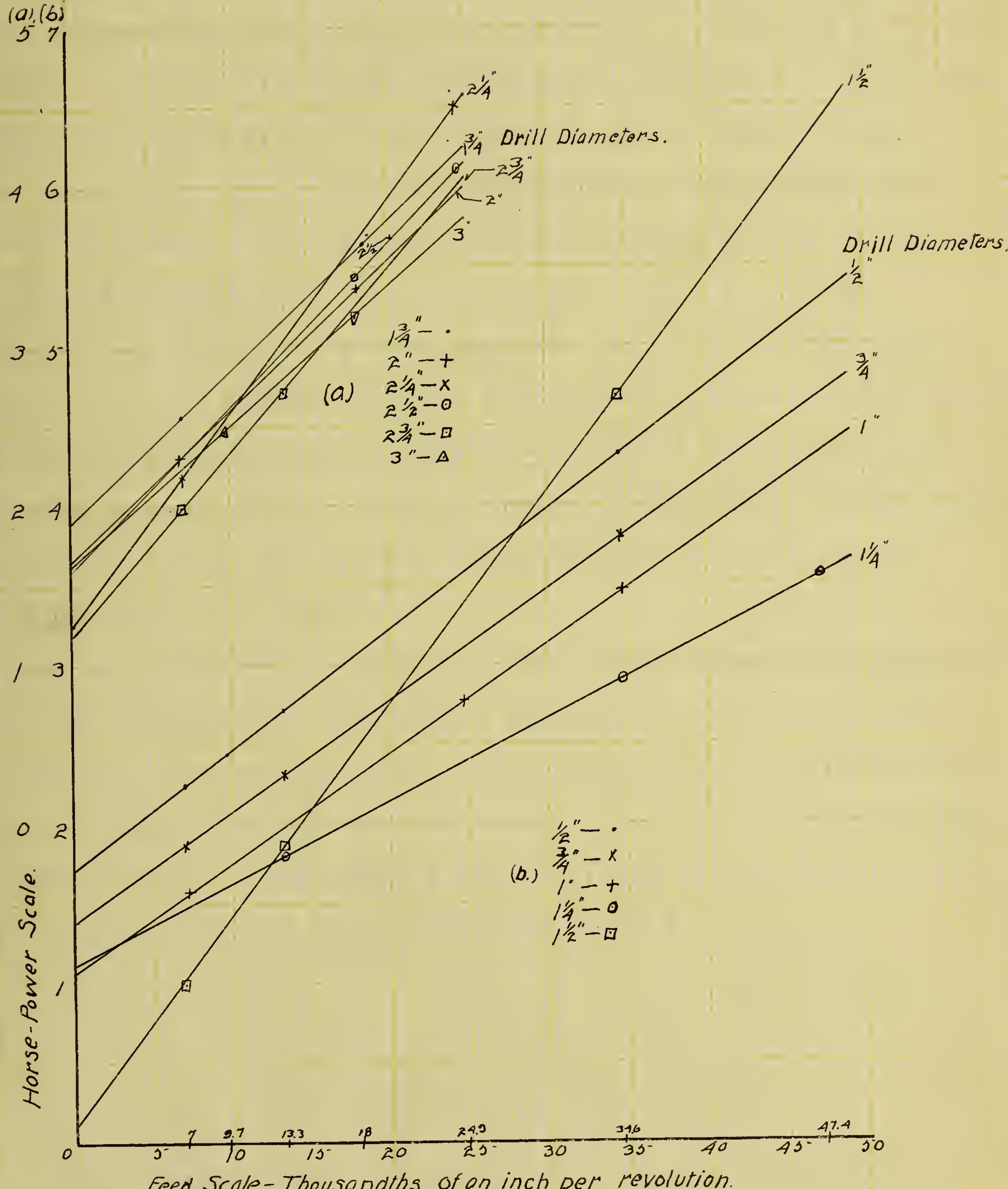
TABLE XI.

BICKFORD RADIAL DRILL ON CAST-IRON

AM. MACH., SEPT. 18, 1902.

No	Diameter of Drill.	Feed Per Revol.	R.P.M.	No. Cubic In Removed Per Min.	H.P. Consumed			H.P. Consumed Per Cubic In.	
					By Machine	By Work	Total	By Work	Total.
34	1½"	.0346	82	5.00	.24	4.57	4.81	.914	.961
35	"	.0474	"	6.84	"	6.11	6.35	.893	.928
36	1¾"	.0070	68.5	1.15	.80	1.37	2.17	1.190	1.890
37	"	.0097	"	1.60	"	1.69	2.49	1.060	1.560
38	"	.0133	"	2.19	"	2.14	2.94	.978	1.340
39	"	.0180	"	2.96	"	2.68	3.48	.910	1.180
40	"	.0249	"	4.10	"	3.39	4.19	.826	1.020
41	2"	.0070	57	1.25	.57	1.31	1.88	1.050	1.500
42	"	.0097	"	1.73	"	1.67	2.24	.966	1.300
43	"	.0133	"	2.38	"	2.04	2.61	.894	1.100
44	"	.0180	"	3.22	"	2.65	3.22	.824	1.000
45	"	.0249	"	4.46	"	3.31	3.88	.742	.870
46	2¼"	.0070	47.2	1.31	.30	1.22	1.52	.931	1.160
47	"	.0097	"	1.82	"	1.73	2.03	.951	1.110
48	"	.0133	"	2.49	"	2.26	2.56	.908	1.030
49	"	.0180	"	3.37	"	3.01	3.31	.893	.982
50	"	.0249	"	4.67	"	4.28	4.58	.916	.980
51	2½"	.0070	39.3	1.35	.30	1.55	1.85	1.150	1.370
52	"	.0097	"	1.87	"	1.90	2.20	1.010	1.180
53	"	.0133	"	2.56	"	2.33	2.63	.910	1.030
54	"	.0180	"	3.47	"	2.95	3.25	.850	.936
55	"	.0249	"	4.80	"	3.81	4.11	.794	.956
56	2¾"	.0070	32.6	1.35	.28	1.06	1.34	.786	.992
57	"	.0097	"	1.88	"	1.57	1.85	.835	.984
58	"	.0133	"	2.57	"	2.17	2.45	.844	.954
59	"	.0180	"	3.48	"	2.83	3.11	.813	.894
60	"	.0249	"	4.82	"	3.65	3.93	.757	.816
61	3"	.0070	27	1.34	.35	1.43	1.78	1.070	1.330
62	"	.0097	"	1.85	"	1.89	2.24	1.020	1.210
63	"	.0133	"	2.54	"	2.34	2.69	.922	1.060
64	"	.0180	"	3.43	"	2.66	3.01	.775	.877
65	"	.0249	"	4.75	"	3.53	3.88	.728	.800

RELATION OF POWER, FEED AND SIZE OF DRILL IN DRILLING CAST IRON FROM THE SOLID.



The diagram or curve gives the relation between the feed and the total amount of power consumed for all the observations. The The vertical scale gives horse-power and the horizontal scale the feed in thousandths of an inch per revolution. The smaller figures just within the base line give the feeds actually used in the tests. The upper left hand part of the diagram gives the data for the larger sizes of drills and for this a second set of horse-power figures are given. The figures for the feed are common to both parts of the diagram.

From these tests it is very apparent that the law connecting the power with the rate of feed is a straight line law. Differences of grinding, of sharpness, and quality in drills themselves naturally enter into the data between different drills, while since these factors are constant for any one drill there is less chance for varying in the latter case.

Some very interesting data is given in the Report of Proceedings of the Institute of Mechanical Engineers for July, 1903, by Mr. Henry H. Suplee of New York. The results were obtained from reports of daily work and are not tests. The discussion following this paper is very interesting from the standpoint of the new steels and some very prominent engineers enter into it.

TABLE XII.

AUTHENTIC REPORT FROM SHOPS OF PACIFIC R.R. OF DAILY WORK.

PROCEEDINGS OF THE INST. OF MECH. ENG'S. JULY. 1903.
H.H. SUPLEE.

Machine Tool.	Material Machined	Speed of Cut Ft. per min.	Feed in.	Lbs. of Metal Per Hour	Depth of Cut in.	R.P.M of Motor	H.P. (Slide Rule)
Boring Mill	(Very Hard) Cast-Iron	18	1/8	—	3/8	900	11.7
88-in Lathe	(Very Hard) Driver Tyre	24	3/32	90	3/8	900	17.3
Planer 30' Table	Cast-Iron	15	1/4	458	9/16	875	22.8

Dr. Hartig has a horse-power formula which is very much in use at the present in all experiments using transmission dynamometers; H. P. = C W, when C in a constant and W equals the weight of chips removed per hour. A similar formula was mentioned on a previous page in connection with the thesis of Victor Sheldon.

The size of the lathe, and, therefore the diameter of work, has no apparent affect on thecutting power. If the lathe be heavy, the cut can be increased and consequently the weight of chips increased, but the value of C appears to be about the same for a given metal through several varying sizes of lathes, averaging .030 for cast iron, .032 for wrought iron and .047 for steel. The first table shows that an average of .26 horse-power is required to turn off 10 pounds of cast iron per hour. Maximum power required per pound of chips in a given time was found to be needed with broad surface cut of .125 inches and a feed of 25.82 feet per minute, while a less power was required when the chip was square, thus agreeing with the previous statements quoted in these pages as made by other engineers.

Horse-power revolution diagram for different size lathes, omitting the power necessary to drive with back gear. The table gives horse-power to run lathes empty at varying speeds. Taking the average for the four lathes, at line AB, we find that it strikes the base line at about .095, showing that about .095 horse-power is required to start lathe when cold, which is considered low.

TABLE XIII.

HORSE-POWER REQUIRED TO REMOVE CAST-IRON IN 20-IN LATHE. J. J. HOBART.

No	No of Trials	Tool Used	Aver. Cutting Speed Ft. per Min.	Depth of Cut in.	Aver. Br'dth. of Cut in.	Aver. H.P.	Lbs. Metal Removed per Hour.	Value of Constant C
1	22	Side Tool	37.90	.125	.015	.342	13.30	.025
2	15	Diamond Point	30.50	"	"	.218	10.70	.020
3	17	Round Nose	42.61	"	"	.352	14.95	.023
4	2	Left Hand R.N.	26.29	"	"	.231	9.22	.026
5	4	Square Faced	25.82	.015	.125	.255	9.06	.028
		Tool ½" Broad				.255		
6	1	" "	25.27	.048	.048	.240	10.89	.018
7	—	" "	25.64	.125	.015	.246	8.99	.027

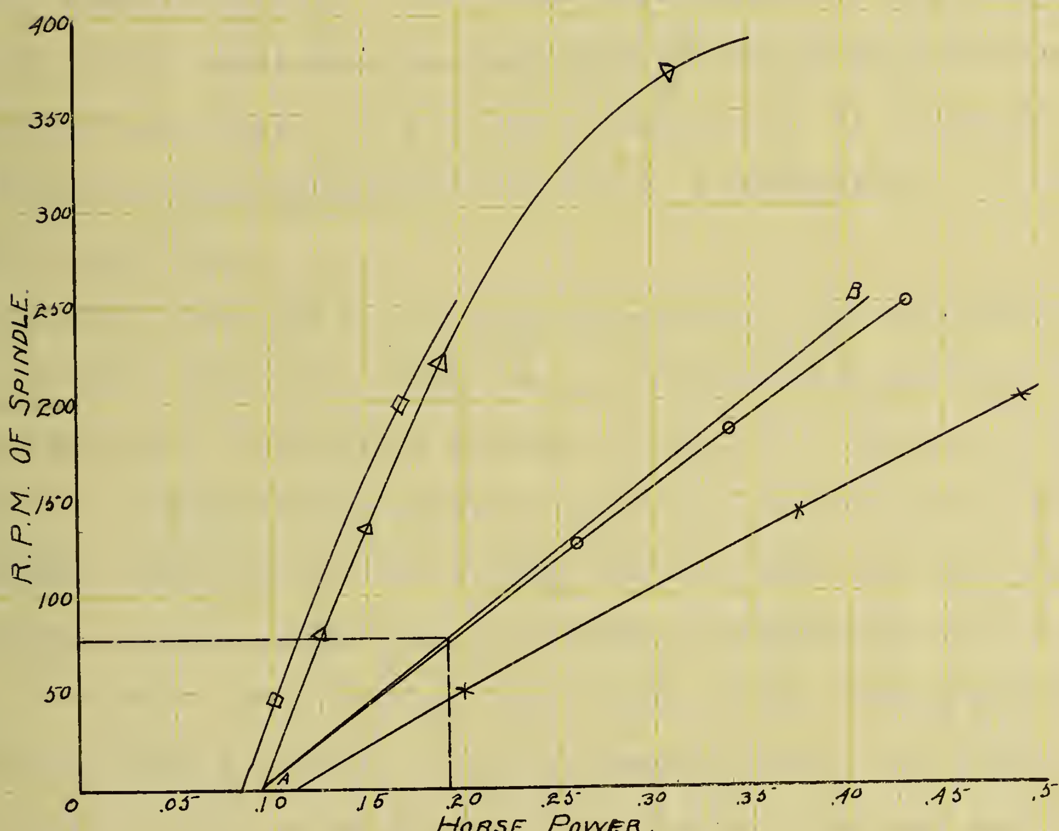
TABLE XIV.

TEST OF 26-IN LATHE R.H. SMITH.

No. of Trials.	Metal.	Cutting Speed Ft. Per Min.	Depth of Cut in.	Aver. Br'dth of Cut in.	Aver. H.P.	Aver. Lbs. Metal Per Hour.	Value of Constant C
4	Cast-Iron	12.70	.050	.046	.105	5.49	.019
4	" "	11.10	.135	.046	.217	12.96	.017
2	" "	12.85	.040	.038	.098	3.66	.027
4	Wrought Iron	9.60	.030	.046	.059	2.49	.023
4	" "	9.10	.060	.046	.138	4.72	.029
4	" "	7.90	.140	.046	.186	9.56	.019
2	" "	9.35	.045	.038	.092	2.99	.031
4	Steel	6.00	.020	.046	.043	1.03	.042
4	"	5.80	.040	.046	.085	2.00	.042
4	"	5.10	.060	.046	.108	2.64	.040

Horse-Power, Revolution Diagram.

□ = Curve For 12-In Lathe.
△ = " " 20- " "
⊖ = " " 13½- " "
X = " " 17½- " "
AB = " " Mean H.P.



The Engineering (London) Magazine for October 30, 1903, gives a complete set of tables on Rapid Cutting Tool Steels, which are very important from the fact that they contain data for all the best tool steels made. Only the last table will be given here since it is the only one for which the horse-power was determined. The lathe loaned by Sir W. G. Armstrong, Whitworth & Company was a 15-inch center screw cutting lathe, taking in a length of 9 feet 6 inches between centers. For these experiments it was fitted with 18 inch center headstock, the special headstock having both double and treble back-gears, the gear ratio being 14.9 to 1 and 42.5 to 1. This headstock was specially fitted with a three-step cone suitable for a 6 inch belt.

The lathe was driven by a direct-current, shunt-wound Schuckert motor of 120 electrical horse-power, supplied with current from the three-wire power leads at a voltage of 220. At every trial observations of the current supplied and of the brush-volts of the motor were made every two minutes during the cut; when the tool had been withdrawn, and the motor speed thereafter readjusted to its average during the test, two readings were taken of the same quantities with the lathe running light. The difference between the electrical horse-power of the motor when driving the cutting tool and when only driving the lathe and intermediate gearing gives the net horse-power required for cutting; assuming that the waste horse-power of the drive remains the same when the lathe is cutting as when it is running light (with the forging in place).

The table gives the results of the trials made with ordinary water-hardened and ordinary Mushet steel tools upon soft steel and medium cast iron. These trials show that 20 feet per minute with a cut of one-sixteenth inch by one-sixteenth inch is the superior

No of Trials.	Tool-Steel Used	Materi Cut.
17	Water Hardened	Soft Ste
18	" "	" "
23	" "	" "
25	" "	" "
19	Mushet	" "
20	"	" "
21	"	" "
24	"	" "
26	High-Speed Air Hardened	" "
75	Water Hardened	(Medium) Cast-Iro
73	" "	"
77	" "	"
70	" "	"
71	" "	"
72	Mushet	"
74	"	"
76	"	"
78	"	"
A 178	Water Hardened	(Soft) Cast-Iro
B 178	"	"
181	Mushet	"

TABLE XV

TEST OF VARIOUS TOOL-STEELS IN 15-IN SPECIAL LATHE

ENG (LON) OCT, 30, 1903

No of Trials.	Tool-Steel Used	Material Cut	Actual			Area of Cut Section Sq. In.	Duration of Trial Min.	H.P. Electrically Measured			Area Machined Sq Ft.		Lbs. Metal Removed		Cause of Withdrawal	Cutting Force on Tool.
			Speed	Cut	Traverse			Gross	Lost	Net	Total	Per Min.	Total	Per Min.		
17	Water Hardened	Soft Steel	31.2	.0585	.0625	.00365	20.0	11.95	9.95	2 00	3.26	.163	7.25	.362	Time Up	2110.
18	" "	" "	25.1	.1765	"	.01104	5.0	8.76	6.17	2 59	0.65	.131	4.00	.800	Tool Failed	3407
23	" "	" "	40.9	.1885	"	.01180	5.8	10.21	6.62	3 58	1.22	.214	9.50	1.650	"	2890
25	" "	" "	61.8	.0620	"	.00378	6.6	12.15	10.00	2.15	2.11	.319	5.25	.792	"	1030
19	Mushet	" "	35.1	.1810	"	.01130	20.0	12.96	9.76	3 20	3.67	.183	27.25	1.362	Time Up	3005
20	"	" "	35.2	.1805	"	.01128	3.2	10.01	5.64	4.37	0 34	.171	3 50	1.105	Tool Failed	4090
21	"	" "	40.5	.1740	"	.01088	13.0	12.30	9 80	2.50	2.75	.211	18.50	1.420	"	2040
24	"	" "	63.0	.0580	"	.00362	17.0	12.25	10.15	2.10	5 55	.326	13.50	.794	"	1019
26	High-Speed Air Hardened	" "	25.4	.2830	.3750	.1065	5.5	34.90	11.49	2 34	0.75	.136	47.00	8.550	Time Up.	30,600
75	Water Hardened	(Medium) Cast-Iron	24.6	.0625	.0625	—	17.0	—	—	—	2.19	.128	3.25	.191	Tool Failed	-
73	" "	"	17.6	.1875	.0625	—	8.4	—	—	—	.77	.091	5.00	.600	"	-
77	" "	"	15.5	.1875	.1250	—	.8	—	—	—	—	—	1.00	1.200	"	-
70	" "	"	15.0	.1875	.1250	Tool refused to cut at 15' per min.					—	—	—	—	"	-
71	" "	"	16.0	.1875	.1250	"	"	" "	" 16'	" "	—	—	—	—	"	-
72	Mushet	"	23.6	.0625	.0625	—	20.5	8.10	—	—	2.57	.122	5.25	.256	"	-
74	"	"	19.1	.1875	.0625	—	12.3	—	—	—	1.22	.099	8.25	.668	"	-
76	"	"	15.0	.1875	.1250	—	1.5	—	—	—	—	—	1.75	1.165	"	-
78	"	"	16.0	.1875	"	—	8.5	—	—	—	—	—	8.00	.940	"	-
178 A	Water Hardened	(Soft) Cast-Iron	22.5	.1010	"	—	8.5	—	—	—	1.00	.117	13.25	1.550	"	-
178 B	"	"	23.1	.1910	"	—	8.8	8.65	6.00	2.65	1.06	.120	13.00	1.480	"	3790
181	Mushet	"	31.6	.1860	"	—	32.8	—	—	—	5.36	.163	73.50	2.250	"	-

limit of speed for ordinary water-hardened steel operating upon Whitworth fluid compressed soft steel; while an ordinary Mushet tool can run at over 30 feet per minute, with a three-sixteenths by one-sixteenths inch cut upon the same material. Experiment No. 26 gives a deduced cutting force of 128 tons per square inch, which figure verifies the linear law variation of cutting force with area of cut.

As can be seen very little is known as yet on this subject of Tool-steels and the Power required to drive machine tools; but the problem is receiving the close and constant attention of the leading engineers of the country and will soon be mastered.

It will cause a revolution in the manufacture of all machines using these high-speed tool-steels as the ones now in use are far too weak to stand the high strains to which they will be subjected in the future.

With the wide spread use of electrity and its simple application to the drive, is is very evident that the motor driven machine tool will soon be installed throughout, thus enabling the manufacturer to determine very easily and at any time the exact amount of power that his machine tools, shafting, etc., absorb even down to individual machines and he can then calculate the cost of production with some degree of accuracy when referred to the individual items.

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